Integrated Plumbing System for the Recovery and Reuse of Household Wastewater

Yanbin Hua[1], Ken Nagasaka[2], Edward Ching-Ruey Luo[3], Chew-Tin Lee[*4], Liulin Li[*1]

[1]College of Horticulture, Shanxi Agricultural University, Taigu, Shanxi, P. R. China

[2]Department of Electrical and Electronic Engineering, Tokyo University of Agriculture and Technology 2-24-16, Nakamachi, Koganei-shi, Tokyo, Japan

[3]Faculty of Department of Civil Engineering, National Chi-nan University, 545 Nantou Taiwan

[4]Department of Bioprocess Engineering, Faculty of Chemical Engineering, Universiti Teknologi Malaysia, 81300 Johor Bahru, Malaysia

[1]huayanbin2011@gmail.com; [2]bahman @cc.tuat.ac.jp; [3]edward.luo@msa.hinet.net; [*4]ctlee@utm.my; [*1]tgliulin@163.com

***Abstract*- Many countries are facing increasing pressure to treat municipal wastewater due to rapid growing population in the urban cities. This paper reports a novel design based on an integrated water plumbing system to treat and reuse the household wastewater. The design facilitates simple and efficient collection, treatment, and reuse of wastewater within a household. The detailed design and operation procedure are presented. Implementation of simple and efficient design within a household is a viable solution to the problems faced by increased pressure on domestic wastewater treatments; it also offers savings to the residents and promotes the concept of green building.**

Keywords*- *Household Wastewater; Integrated Plumbing System; Recovery and Reuse of Wastewater; Multilayer Filter

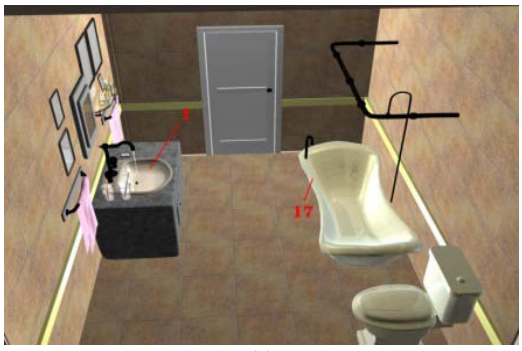
I. INTRODUCTION

Due to rapid development and urbanization, water consumption and demand has increased significantly in recent years. Domestic sewage is the main source of wastewater [1] that takes 75% of the total amount [2]. The mass discharge of domestic sewage has imposed great negative effect on the environmental-friendly development of the cities worldwide. For instance, in the last century, China was listed as one of the 13 countries that have faced water shortage crisis and would severely impact the sustainable development of China. In China, the recovery and reuse of wastewater only reach about 33%; the percentage is much higher in the developed countries (75% ~ 85%). The main reason is that the development and application of water saving products are intensively implemented in the developed countries such as the United States of America [1]. Many advanced and efficient techniques are developed for water saving. According to an investigation in the USA, it was evidenced that in New York the main source of the household wastewater is from toilet flush (40%) and followed by the shower and bathtub (30%), laundry (15%), kitchen use (10%), and other uses (5%) [3]. In the urban areas in many countries, water used for flushing toilet accounts for 40% to 50% of the total water used.

Hence, recovery and reuse of the household wastewater can significantly relief the pressure of water demand and discharge, notably in the cities with high population density. In this paper, an innovative and integrated water plumbing system is designed within a household for the effective recovery and reuse of household wastewater, notably that from the toilets. The design helps to promote green building with less water demand and discharge. It also promotes water-saving consumption habit and higher consciousness on environmental protection as a whole.

II. THE INTEGRATED WATER PLUMBING SYSTEM

An integrated water plumbing system is designed to recover and reuse wastewater within a household. The design is proposed based on a model double-storey apartment with toilet located separately in the upper and lower floor of the house unit as shown in Fig. 1 (3D design) and Fig. 2 (1D design), respectively.



(a)

(b)

Fig. 1 The 3D design of two toilet rooms in a double-storey apartment chosen as a model for wastewater recovery and reuse: (a) upper storey; (b) lower storey

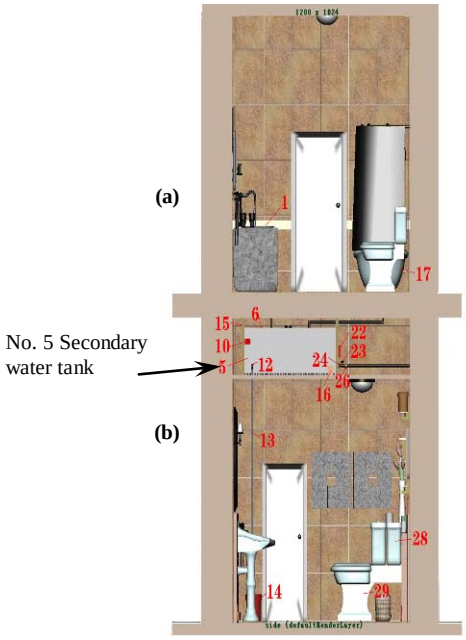


Fig. 2 1D design of the model system: (a) upper storey; (b) lower storey

The overall concept is that the wastewater generated from the primary collection sources in the upper storey as shown in Fig. 1(a) and 2(a) (No.1 wash basin, and No.17 bathtub) is primarily clarified through the integrated plumbing system while being channelled to the secondary water tank as shown in Fig. 2. The primarily clarified water is collected in the secondary water tank for reuse in the toilet located in the lower storey as shown in Fig. 1(b) and 2(b) (No.14 collection bucket and No.28 toilet tool). Clearer illustration of the secondary water tank and the entire integrated water plumbing system interconnected mainly by the hosepipes No. 4, 13, 20 and 25 are shown in Fig. 3.

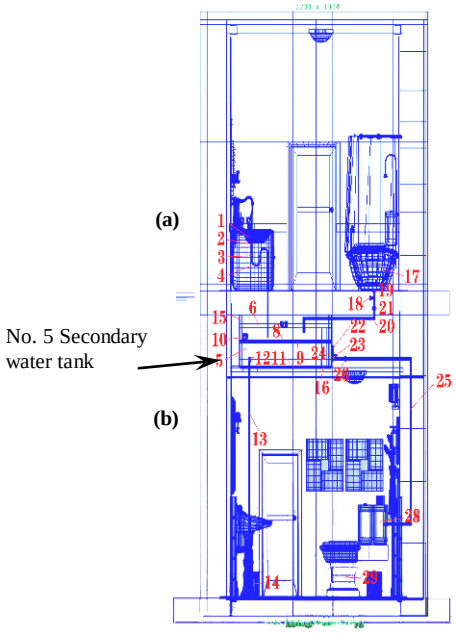


Fig. 3 Illustration of the secondary water tank and the integrated water plumbing system interconnected mainly by hosepipes No. 4, 13, 20 and 25

All parts as labelled by No.1 to No.29 are listed in Table I. The labelling is valid for Fig. 1 to Fig. 5.

TABLE I LABELING OF PARTS IN FIG. 1 TO FIG. 5

No.	Part
1	Wash basin (primary water collection tank) in the upper toilet
2	Filter
3	Detergent holder
4	Connecting S-hosepipe between primary water tank No.1 and the secondary water tank No.5
5	Secondary water tank
6	The cover of the secondary water tank No.5
7	Not available
8	Part of multilayer filter for the clarification of non-greasy wastewater in the secondary water tank No.5
9	Part of multilayer filter for the clarification of greasy wastewater in the secondary water tank No.5
10	Alarm device for the secondary water tank No.5
11	Detergent holder
12	Water outlet switch
13	Connecting hosepipe between the secondary water tank No.5 and the water collection bucket No.14
14	Water collection bucket in the lower toilet
15	Support holder for the secondary water tank No.5
16	Slagging hole at the bottom of the secondary water tank No.5
17	Bathtub (primary water collection tank) in the upper toilet
18	Water outlet switches
19	Filter
20	Connecting hosepipe between the primary water tank No.17 and the secondary water tank No.5
21	Detergent holder
22	Water level controller
23	Water outlet switch
24	Filter
25	Connecting hosepipe between the secondary water tank No.5 and toilet tool No.28
26	Detergent holder
27	Not available
28	Toilet water tank with valve in the lower toilet
29	Toilet bowl in the lower toilet

Referring to Fig. 1 through Fig. 3, wastewater is collected mainly from the wash basin (No. 1) and bathtub (No. 17) in the upper toilet through gravity to the secondary water tank and reused in the lower toilets, namely to No. 14, the collection bucket and No. 28, the toilet tool for toilet flushing.

The wastewater will be primarily processed *in-situ* through the integrated plumbing system supplied with detergents within the pipes. The wastewater will then be collected in the secondary water tank (No. 5) through gravity that is located in between the upper and lower storey. The key feature of the entire design, which is basically based upon an ordinary toilet design of a double-storey apartment, attributes to this extra unit of secondary water tank for secondary wastewater sanitization. The secondary water tank is installed with a novel multilayer filter which mainly consists of layer No. 8 and No. 9 for effective treatment of non-greasy and greasy wastewater, respectively. The treated water would be tasteless, odourless and sanitized.

The entire design offers overall simplicity and ease of implementation based on the existing toilet layouts with only the addition of one extra unit operation, i.e. the

secondary water tank (No. 5); and facilitated by the integrated design of the water plumbing system as shown in Fig. 3. Hence it would be much more cost effective if such design is incorporated into the green building from the stage of building design before construction.

A. Detailed Design of the System

The majority parts of the toilets consist of the ordinary materials for toilet design except for the secondary water tank. The WC unit is the ordinary one consisting of No. 28 the water storage tank with valve and No. 29 the toilet bowl. The Secondary water tank is the key unit for water collection and wastewater clarification. There is a novel multilayer filter (No. 8 and No. 9) built within this secondary water tank that is the highlight of this paper as shown in the 3D design of the secondary water tank in Fig. 4.

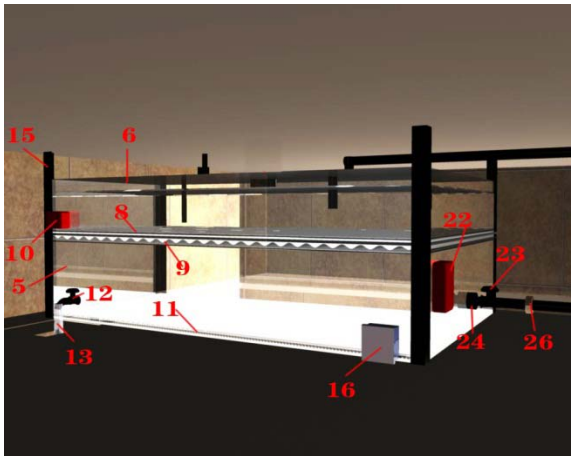


Fig. 4 The 3D design of the secondary water tank built with the novel multilayer filter (No.8 and 9)

Referring to Fig. 4, the secondary water tank consists of an organic glass water tank (30 cm in height, 50 cm in length and 40 cm in width) with cover (No. 6). The multilayer filter (No. 8 and No. 9) is fixed close to the central part of the secondary water tank. Filter No. 8 is a composite structure consists of a renewable rigid steel clapboard with holes (1 mm in diameter, 100 μm in thickness) combined with a layer of active carbon 200 μm in thickness. Filter No. 9 consists of a combined layer of filtering membrane (thickness of 100 μm, pore size of 0.03 cm in diameter) and an iron filter net (0.5 cm in thickness and mesh size of 0.05 cm in diameter).

The secondary water tank is connected with the water hosepipes (No. 13 and No. 25) (1.5 cm in diameter; 300 cm - 400 cm in length), water faucet or the water outlet switches (No. 12 and No. 23) and a fixed support (No. 15) for the secondary water tank.

For wastewater sanitization, the hosepipes (No. 4, No. 13, No. 20 and No. 25) and secondary water tank (No. 5) are designed to hold the detergents such as muriatic acid, gelatin, glyoxalin and hexamethylenetetramine; and deodorants such as zeolite, magnesium chloride, magnesium oxide and benzoic (No. 11). Several filters consist of the filtering membrane (thickness is 100 μm, pore size is 0.03 cm in diameter) and filter iron net (mesh size is 0.05 cm in diameter) are used to purify the wastewater in the first level water tank (No. 1 and No. 17) as primary clarification for the wastewater. Referring to Fig. 3, the filters (No. 2, No. 19, No. 24) are fixed at the neck of the hosepipes and the necks of the water inlet/outlet switches (No. 18 and No. 23) as connected to the first level water tanks (No. 1 and No. 17) and the secondary water tank (No. 5). Two water outlet switches (No. 18 and No. 23) are connected with the water hosepipes (No. 20 and No. 25). These switches are open by default and expected to be in operation for all time except during maintenance and tank cleaning.

For water control into toilet tool No. 28, it is proposed that the clean water supply into the toilet tool No. 28 is typically switched off manually so that water supply is from the secondary water tank by default. Occasionally if the water supply is not sufficient, the clean water supply to the toilet tool No. 28 can be turned on. Unless the water supply from the secondary water tank is rather inconsistent, the arrangement can be reverted to normal operation where demand on treated water is on occasional use basis.

For water control into bucket No. 14, a simple valve is fixed at the end of the hosepipe No. 13 close to the bucket for manual control of the water flow which was not labeled in all figures.

Referring to Fig. 4, the secondary water tank is divided into two chambers by a multilayer filter consists mainly of filter No. 8 and No. 9. Wastewater flows into the upper chamber and gets clarified in the lower chamber after passing through the multilayer filter. Filter No. 8 is essential and sufficiently effective to treat the non-greasy wastewater where particulate and impurities are removed. Filter No. 9 is optional to make the treatment process more effective for greasy wastewater. Filter No. 9 contains a layer of active carbon for the removal of dirt, odor and absorbing the oil from the greasy wastewater.

On the side wall of the secondary water tank (No. 5), a water level controller (No. 22) and an alarm device (No. 10) are in place to warn the overflow in case the water level controller is malfunction, as shown in Fig. 4. Scheduled cleaning of the tank is essential to avoid the accumulation of excessive drosses and to ensure effective operation of the system. There is also a slagging hole (No. 16) at the bottom of the secondary water tank that is usually closed [4]. The slagging hole is used for discharging drosses after users clean the secondary water tank. In order to make a good overall arrangement and use the room space efficiently, the secondary water tank should be lifted high on the wall by the fixed support (No. 15).

B. Integrated Water Plumbing System for Wastewater Collection and Reuse

Fig. 5(a) shows the primary wastewater collection part in the upper toilet. There are two water outlet switches (No. 12 and No. 23, open by default) from the secondary water tank (No. 5) and these outlet switches are connected to the treated water collection bucket (No. 14) and toilet tool (No. 28) in the lower toilet. They are connected by the water

hosepipes (No. 13 and No. 25). The water outlet switch (No. 23) and water hosepipe (No. 25) are supplied with adequate amount of detergents (No. 26). The treated water collected in the collection bucket (No. 14) can be reused for other cleaning purposes such as floor washing.

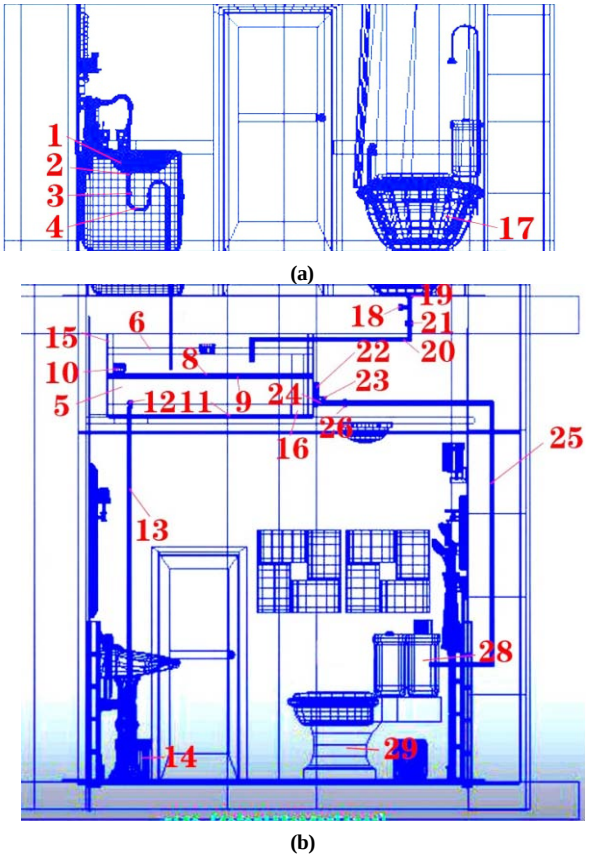


Fig. 5 Integrated water plumbing system for wastewater (a) collection and (b) reuse

III. ADDITIONAL DESCRIPTION

A. Decontamination Part

For the primary wastewater treatment, the connection between S-shaped water hosepipe (No.4) and wash-basin (No. 1) is equipped with the filter (No. 2) as described earlier. In addition, the interconnecting hosepipes (No. 4, No. 20) are installed with detergent holders (No. 3, No. 21) to dispense detergents (eg. muriatic acid, gelatin, hexamethylenetetramine and glyoxalin) within the hosepipes while wastewater flows through. This would minimize the amount of unclean mass from being transferred into the next procedure as well as cleaning the hosepipes. After this primary wastewater treatment *in-situ*, water flows into the secondary water tank (No. 5) through the S-shaped water hosepipe (No. 4), water hosepipe (No. 20) and the cover of the secondary water tank (No. 6).

B. Reuse of the Treated Wastewater

The water treated primarily flows through the water outlet switches (No. 12 and No. 23) on the lateral sides of the secondary water tank through the water hosepipes (No. 13 and No. 25) which are equipped with detergent holders (No. 11 and No. 26 respectively) into the treated water collection devices in the lower toilet, namely collection bucket (No. 14) and the toilet tool (No. 28), respectively.

In addition, there is a filter (No. 24) installed between water outlet switch (No. 23) and the water hosepipe (No. 25) that is the same as the ones for No. 2 and No. 19, hence the wastewater is cleansed for the third time.

The system developed in this study should incur low-cost as no extra operating power is needed. The design also occupies minimum space due to the addition of only one unit operation (No. 5). Automatic disinfection and deodorization are special features for this system. The system would ensure that the water recovered is odorless and tasteless. Finally, no other negative effects or noises are anticipated during the entire working process.

C. Protection and Cleaning of the System

For long term maintenance of the device, the system should be well protected and periodically cleaned. At a regular schedule, the water hosepipes and filters should be cleaned, including the filtering membrane and the filtering iron net. Detergents in the hosepipes should be replenished with new detergents. The dirt at the bottom of the secondary water tank and the overall secondary water tank must be cleaned as scheduled. During the cleaning process, all the separating board, filtering membrane and filtering iron net in the secondary water tank should be dismantled, cleaned, all waste removed before being restored to operation condition. This will ensure safe daily operation and good quality of the treated water.

IV. CONCLUSIONS AND RECOMMENDATIONS

Apparently, recovery and reuse of household wastewater from toilet plays a very important role in significantly saving and recovering the water resource in sustainable manners. This paper highlights the design of a household wastewater recovery system based on an integrated water plumbing system with minimum modification on the ordinary household toilet design in a model double-storey apartment. It mainly needs the installation of an extra unit of secondary water tank for water clarification so that the treated water can be reused for general household cleaning purposes. The entire design relies on an innovative water plumbing system between the toilet in the upper floor which is channeled to the toilet in the lower floor by gravity and without the need of extra power consumption. This design, if adopted directly to the new buildings, can significantly reduce the household water consumption and quantity of wastewater effluent and with great effect on shaping resources-saving society in long run.

There is still great potential for further improvements of the current system so that the treated water can be reused for wider applications. Notably, on applications for irrigating crops such as the flowers, fruits and vegetables, and even for human consumption, it is likely that bioremediation using safe and efficient microbial inoculant to disinfect the

wastewater is a promising way to sanitize and deodorize the wastewater for such purposes.

V. INTELLECTUAL PROPERTY

The multilayer filter structure for the recovery and reuse of wastewater has been authorized by the Chinese New Practical Patent (Patent No.ZL201120059056.6).

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Y. B. Hua was born in Shanxi, China, in 1990. He studies in College of Horticulture of Shanxi Agricultural University. He has published four scientific papers and has been granted two Chinese New Practical Patents (ZL201120106523.6 and ZL201120059056.6).

He has attended the International Conference on Materials Science and Information Technology sponsored by Singapore Institute of Electronics (ICMSIT 2011, Singapore, 2011.9.16-9.18). The paper submitted to the conference has been indexed by EI Compendex. His major research fields are horticultural facilities and medicinal ornamental flowers.

K. Nagasaka was born in Kermanshah, Iran, in 1956. He received the B.S. degree in electrical engineering from Nihon University, Tokyo, Japan, in 1985; and the M.S. and Ph.D. degrees from Tokyo Metropolitan University, Tokyo, Japan, in 1987 and 1990, respectively. From 1990 to 1991, he was a chief researcher for a computer software development company in Tokyo, Japan. From 1991 to 1994, he was a visiting professor in the University of Manitoba, Winnipeg, Canada. From 1994 to 1998, he was a scientist in the Central Research Institute of the Electric Power Industry, Tokyo. From 1995 to 1998, he was an associate professor in the Department of Electrical Engineering, Tokyo Metropolitan University. He is currently an associate professor in the Department of Electrical and Electronic Engineering, Graduate School of Engineering, Tokyo University of Agriculture and Technology, Tokyo, Japan. He has published more than 600 scientific papers, and many of them have won paper prizes, including the Institute of Electrical Installation Engineers (IEIE) of Japan in 1991. Professor Nagasaka was a recipient of three awards from the PSC in 2001, 2002, and 2006. Also, in 2006, he was a recipient of a medal from the University of Tehran, Tehran, Iran, for his contribution to the First Conference on Control and Management of Energy Systems. His current research projects concern environmental energy engineering, particularly power system analysis, power deregulation, wind power, micro-grid, smart grid, energy saving, load forecasting, and application of intelligent systems to power systems. He is a member of the IEEE.

C. T. Lee was born in Seremban, Malaysia in 1972. She currently serves as an associate professor in the Department of Bioprocess Engineering, Faculty of Chemical Engineering, Universiti Teknologi Malaysia (UTM). She completed her Bachelor and Master Degree of Bioprocess Engineering in the same department in year 1996 and 1998 respectively. She pursued her PhD in Engineering (Biochemical), University of Cambridge, United Kingdom from 1999-2003. She specializes in application of microbial technology on organic waste management and bioremediation, notably in the area of sustainable soil management, composting and formulation of microbial inoculant. She involves actively in a SATREPS project entitled Development of Low Carbon Society for Asian Region as funded by JICA-JST (Japan) from 2011-2016. She is the associate member for Board of Engineering Malaysia, Institute of Engineer Malaysia and Institution of Chemical Engineers, UK.

Edward, C. R. Luo was born on 21, March 1957 in Taiwan. He has PhD degree in Business Administration Management, (PALLADIUM University, PALLAMA, 2004-2007) with major in Conflict and Strategic Management; PhD in Psychology (University of Central Nicaragua, NICARAGUA) with major in Theory and Practice on Psychotherapy and Counseling (1990—1993) and PhD in Hydrodynamics Engineering (Asian Institute of Technology, Thailand) with Major in River, Estuary, Marine, Ecological Engineering, and Debris Flow Engineering.

He has the following professional memberships as follow:2007 to now: Deputy Director General (DDG) of International Biographical Centre (IBC), Cambridge, England;2006 to now: Committee Member on Research and Development of American Biographical Institute (ABI) U.S.A; Certified Licenses: EMF, International Engineers (Hydraulic Engineering); Asia-Pacific Engineers (Hydraulic Engineering); Senior Professional Hydraulic Engineer (P.E.), Taiwan; Arbitration Member, Taiwan.

L. L. Li was born in China in May 1970. He received the Ph.D. degree from the Nanjing Agriculture University in 2007. Prof. Li started his academic career in Shanxi Agriculture University since 1997. He focuses on the physiological research of fruit crops, specializing in the quality development of pears and jujubes.